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# Feasibility study on the DFP adoption of medical cyclotron decommissioning in the Republic of Korea*

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Since the development of positron emission tomography in 1937, the number of medical cyclotrons used in producing radioisotopes (RI) has risen sharply. In its operation, the structural materials of a medical cyclotron and the concrete shielding of its vault are activated by neutrons. In analyzing domestic and international decommissioning practices, the dismantling characteristics of medical cyclotrons result in a large amount of radioactive wastes, such as concrete, although their activity level is very low. In the United States, the dismantling plan must be established by the applicant. The decommissioning funding plan (DFP) is a financial assurance demonstration based on a site-specific cost estimate of decommissioning the facility. In 10 CFR 30.35, NRC requires the submission of DFP in the case of the possession and use of unsealed byproduct materials with a half-life of greater than 120 days and in quantities exceeding $10^5$ times that of the applicable quantities. The dismantling of the Seoul National University Hospital (SNUH) cyclotron (TR-13) was performed in December 2012. Some of the risks resulting from this dismantling are related to radioactive wastes, as well as issues concerning dismantling costs. Hence, we propose introducing the DFP at the authorization stage. DFP will be helpful in preparing reliable decommissioning plans for safe decommissioning and unexpected early decommissioning in the future. DFP can also contribute in reducing radioactive waste and in decreasing the decommissioning cost by preventing excessive establishments. This study provided an overview of the decommissioning aspects of the SNUH cyclotron and the necessity of adopting the DFP for decommissioning medical cyclotrons.

Keywords: Medical cyclotron, Decommissioning, Decommissioning funding plan (DFP)

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## I. INTRODUCTION

Cyclotrons have a mechanical life of 30–40 years. However, an examination of dismantling practices reveals that early decommissioning often occurs because of changes in the mission, movements, and upgrading, rather than because of age-related defects. Since the development of positron emission tomography (PET) in 1937, the number of medical cyclotrons used in producing radioisotopes (RI) has risen sharply. In a cyclotron, charged particles are injected into a vacuum chamber subjected to a magnetic field. During the operation of the medical cyclotron, its structural materials and the concrete shielding of its vault are activated by neutrons [1–4]. Most medical radionuclides are transitory and quickly decay into acceptable levels. An analysis of domestic and international decommissioning practices shows that medical cyclotrons, which are often housed in large and thickly walled concrete structures, are subject to the activation of trace elements in these materials and produce large quantities of low radioactive wastes [4–7], thus increasing decommissioning costs. Hence, the dismantling of cyclotrons becomes necessary. The procedure of dismantling a cyclotron should be carefully prepared and properly managed to reduce the cost of cyclotron decommissioning.

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## II. ANALYSIS OF DECOMMISSIONING CYCLOTRON IN THE REPUBLIC OF KOREA

This section provides an overview of the decommissioning aspects of the Seoul National University Hospital (SNUH) cyclotron and some recommendations to improve the regulatory system for the safe dismantling of medical cyclotrons.

In December 2012, the medical cyclotron (13 MeV, TR-13) operation was decommissioned and relocated from SNUH to Sungkyunkwan University in the Republic of Korea (Fig. 1). The SNUH cyclotron was built in 1994 and was specifically operated for research and medical RI production in the past 17 years.

### A. Process of SNUH cyclotron dismantling

Before dismantling the cyclotron, the radiation and contamination were surveyed, and the activation of targetry and stopper were checked. The cyclotron was dismantled in the following order to reduce radiological hazards (Fig. 2): (1) ion extractor, (2) targetry 2 EA, (3) ion source, (4) power and manipulation cabinets 4 EA, (5) shielding housing 6 EA, (6) magnet 2 EA, (7) removal of the rail, and (8) transport of all packages. The magnet and shield, weighed about 80 tons, were removed, and the sizes were reduced. The parts of the vacuum electromagnetic and Dee were protected from damage, such as scratches. All project personnel, including eight dismantling personnel, nine moving personnel, and an appointed manager responsible for effective radiation safety, were trained prior to the start of the work activities. The

health physics manager of the decommissioning project recommended that the project safety procedures and criteria for decontamination and decommissioning (D&D) activities be as low as reasonably achievable (ALARA).

### B. Main consequence of decommissioning the SNUH cyclotron

The maximum surface exposure level was measured to be approximately 1.4 mSv/h at the stopper because of proton contamination with few resilient RI, as shown in Table 1. The total collective dose from the decommissioning project was 0.48 person-mSv. The detailed results of the radiation survey were 0.3 mSv in dismantling and transport operations and 0.18 mSv in safety management operations. Table 2 shows the amount of radioactive waste during the dismantling of the cyclotron.

### C. Legal system for cyclotron decommissioning

The SNUH principal communicated with the Korea Institute of Nuclear Safety and the regulatory authorities in April 2012. The ACT Corporation determined the best way to perform the decommissioning task. The D&D project took six months to complete (including the preparation time, dismantling, and transport operations, which took 60 days). All applicants for the authorization of the use of the medical cyclotron are required to submit a license application, including a radiation safety report and rules for safety management, to the Republic of Korea. Thus, after the shutdown of the facility or cyclotron decommissioning, the decommissioning plan is considered independently of the approval of the installation. An initial decommissioning plan for the shutdown of the SNUH cyclotron was prepared and submitted by the applicants.

Fig. 1. (Color online) SNUH Cyclotron(13 MeV, TR-13 Ebco).


Fig. 2. (Color online) Procedures of D&D project (SNUH cyclotron).

## III. PROPOSAL FOR SAFE AND ECONOMIC CYCLOTRON DECOMMISSIONING

### A. Analysis of SNUH cyclotron decommissioning problem

Information and documentation pertaining to the SNUH facility construction and its dismantling techniques are lacking. The main problem encountered was the huge amount of radioactive wastes during the dismantling (Table 1), although the activity level was very low. The dismantling was performed to relocate the cyclotron, the cost and labor incurred were higher than the original plan. The estimated total cost, including the safety administrative cost, was \$270 000. Given this problem (high dismantling costs), commercial hospitals are reluctant to dismantle medical cyclotrons. The D&D costs of medical cyclotrons are expected to increase in the future depending on the amount of waste and disposal, such as concrete.

### B. Introduction of the decommissioning funding plan (DFP)

In the United States, the DFP must be established by the applicant. The DFP is a financial assurance demonstration based on a site-specific cost estimate for the decommissioning of the facility. In 10 CFR 30.35, NRC requires the submission of a DFP in case of the possession and use of unsealed byproduct materials with a half life of greater than 120 days

Table 1. Type of transport package and major properties

| | Bin(Stopper, Targetry) | Body(Magnet, Cover) | Shielding Housing |
|---|---|---|---|
| Radioisotope* | $^{22}$Na, $^{54}$Mn, $^{56}$Co $^{58}$Co, $^{60}$Co, $^{65}$Zn | $^{54}$Mn, $^{22}$Na, $^{56}$Co, $^{40}$K, $^{60}$Co, $^{65}$Zn | $^{54}$Mn, $^{40}$K, $^{60}$Co |
| Maximum estimated radioactivity (MBq) | 61.61 | 500 | 92.3 |
| Surface dose rate (mSv/h) | 0.5 | 0.0005 | 0.005 |
| Weights (kg) | 11.2 | 20,000 | 9,230 |

Table 2. The volumes of radioactive waste generated from SNUH cyclotron

| Category | Weight(ton) | Feature |
|---|---|---|
| Combustible paper | 200 | Decontamination facilities |
| Combustible plastic | 900 | Byproduct & Workers wearing |
| Combustible timber | 1100 | Byproduct |
| Non-combustlble concrete | 10 | Remove contaminated parts |

and in quantities exceeding $10^5$ times the applicable quantities. DFP should be prepared without delay, and the following information must be included in the DFP [8]:

i. A detailed cost estimate for the decommissioning that reflects:

(A) the cost of an independent contractor to perform all decommissioning activities;

(B) the cost of meeting 10 CFR 20.1902 criteria for unrestricted use, provided that the applicant or licensee can demonstrate its ability to meet the provisions of 10 CFR 20.1403 (the cost estimate may be based on 10 CFR 20.1403 criteria);

(C) the volume of onsite subsurface material containing residual radioactivity requiring remediation to meet the criteria for license termination; and

(D) an adequate contingency factor.

ii. Identification and justification for the use of the key assumptions contained in DCE.

iii. A description of the method to assure funds for decommissioning from paragraph (f) of this section, including the means of adjusting the cost estimates and associated funding levels periodically over the life of the facility.

iv. A certification by the licensee that financial assurance for decommissioning has been provided in the amount of the cost estimate for the decommissioning.

v. A signed original of the obtained financial instrument to satisfy the requirements of paragraph (f) of this section (unless a previously submitted and accepted financial instrument continues to cover the cost estimate for the decommissioning).

West Virginia University intended to install the ion beam application (IBA) PET trace self-shielded cyclotron for $ 150,000 of the DFP cost. This estimate was not feasible under the safe decommissioning cost using current radiological data. NRC required $ 356,263.68 for DFP cost in detail and also refused to authorize the submission of insufficient DFP [9].

## IV. RESULTS AND DISCUSSION

The problem with the statute is that the decommissioning plan should be submitted by the applicant before the instrument approval of the medical cyclotron, which is not the case however in the Republic of Korea. Henceforth, the basis of decommissioning preplanning should be reviewed during the installation of the cyclotron itself to encourage each cyclotron user to take responsibility for safe decommissioning actions. Beyond the cause and effect that provided essential input to this study and addressed an appropriate solution of issues related to medical cyclotron decommissioning, we are considering the introduction of DFP at the authorization stage. Preparing reliable decommissioning plans for future safe decommissioning and unexpected early decommissioning will be helpful. DFP can also contribute to the reduction of radioactive wastes and decrease the decommissioning cost by preventing excessive establishments.

### A. Expectation from the adoption of DFP

The decommissioning of medical cyclotron is set to become an increasingly important issue in the Republic of Korea in the future. According to the results of the DFP adoption [10–12], DFP offers a decommissioning plan overview, which covers the financial problem underlying the disposal of radioactive wastes and preparatory measures for appropriate dismantling strategies.

### B. Future consideration for the adoption of DFP

In the current domestic situation, additional research on the adoption of DFP is necessary. First, the standard data on decommissioning medical cyclotrons to estimate the DFP cost and the revision of the rules and regulations should be modernized. Second, if the cost of the entire decommissioning process is not well planned, then the procedure should demonstrate the alternatives and legitimacy of all the various

funding plans. The expiration date for relevant documents and records should be recent by the time of the operation of the cyclotron facilities and should be regularly complemented.


[1] IAEA, Decommissioning of Small Medical, Industrial and Research Facilities, IAEA technical report series No. 414, 2003.
[2] IAEA, Decommissioning of Medical, Industrial and Research Facilities, IAEA safety standard series NO. WS-G-2.2. 1999.
[3] IAEA, Decommissioning of Facilities Using Radioactive Material, IAEA Safety Requirements No WS-R-5, 2006.
[4] Calandrino R, del Vecchio A, Savi A, *et al*. Health Phys. 2006, **90**: 588–596.
[5] Collins E L, Boyance J, Clark F R, *et al*. Decontamination and Decommissioing of the 60" cyclotron facility at Argonne Bational Laboratory-East Project Final Report, ANL, 2011.
[6] European Commission Nuclear Safety and the Environment, Evaluation of the Radiological and Economic Consequences of Decommissioning Particle Accelerators, REPORT EUR 19151, March 1999.
[7] IAEA, Management of small quantities of radioactive waste, IAEA-TECDOC-1041, 1998.
[8] U.S. NRC. Financial assurance and recordkeeping for decommissioning (10 CFR 30.35), http://www.nrc.gov/reading-rm/doc-collections/cfr/part030//part030–0035.html
[9] U.S. NRC, International Cyclotron, Inc. Notice of violation and proposed imposition of civil penalties - $7000 – and order suspending licensed activities within 60 days (ML11347A244), December 23, 2001. http://pbadupws.nrc.gov/docs/ML1134/ML11347A244.html,
[10] NUCLEAR ENERGY INSTITUTE, Used Fuel and Waste Diposal Decommissioning Nuclear Energy Facilies, June 2013.
[11] Energy Fuels Resources Corp., Pinon Ridge Mill Decommissioning Funding Plan, May 2013.
[12] EDF/FRAMATOME, Development of methodology for cost calculations of decommissioning operations, Task 1, 2000.